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MEASUREMENT OF THERMAL PROPERTIES OF INFRARED MATERIALS (PREPRINT)

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Survivability and Sensor Materials Division

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14. ABSTRACT
The thermal properties of several semiconductors including InAs, InSb, Si and HgCdTe have been measured using the laser flash method. The values of the thermal diffusivity, specific heat, and thermal conductivity are reported for these materials at temperatures ranging from 90 to 400K.

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Measurement of Thermal Properties of Infrared Materials

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The thermal properties of several semiconductors including InAs, InSb, Si and HgCdTe have been measured using the laser flash method. The values of the thermal diffusivity, specific heat, and thermal conductivity are reported for these materials at temperatures ranging from 90 to 400K.

The thermal properties of materials are important for understanding and modeling how materials behave in a variety of thermal and thermo-optical conditions. Detailed knowledge of thermal parameters is particularly important for materials used in infrared detectors or as infrared optics. Semiconductor materials used in infrared detectors need to withstand cryogenic temperatures and materials used as infrared optical elements, for example in high-power laser systems, typically need to withstand very high temperatures. In these applications, therefore, it is useful to know the thermal properties of the materials as a function of temperature.

Many methods for directly measuring thermal conductivity require large specimen sizes, which can be difficult to obtain for novel materials as fabrication techniques are typically quite involved. The laser flash method used for measuring thermal diffusivity and specific heat can accommodate significantly small sample sizes (8 mm square, <1 mm thick).[1-3] The thermal conductivity k is calculated from the measured values of the thermal diffusivity K, the specific heat c_p , and the sample density ρ using the relationship[1]

$$k = \mathrm{K} c_p \rho \,. \tag{1}$$

Measurement of thermal diffusivity was carried out by rapidly heating one side of the sample with a near-IR laser pulse with a pulse width of several hundred microseconds. The temperature rise curve was measured on the opposite side of the sample with an IR detector, and the time required for the heat to travel through the sample and cause the temperature to rise on the rear face was used to measure the through-plane diffusivity.[1-3] Measurement of specific heat capacity was made simultaneously with thermal diffusivity by comparing the temperature rise of the sample to that of a reference sample tested under identical conditions.[1]

Thermal conductivity, thermal diffusivity and specific heat were determined as a function of temperature for InAs, InSb and Si, and for bulk $Hg_{1-x}Cd_xTe$ samples having a variety of

compositions. Figures 1 and 2 show the transmission spectra of the samples at 300 and 77 K. Thermal diffusivity and specific heat measurements were performed by Netzsch Instruments, Inc. at 90, 148, 298 and 400 K by the laser flash method utilizing a Holometrix Thermaflash 2200 instrument.[4] Both the instrument and method conform to ASTM E1461-01, *Standard Test Method for Thermal Diffusivity by the Flash Method*.[5] The samples were diced to approximately 8 mm square and the thicknesses ranged from 0.75 to 2.10 mm. They were coated on both sides with a 0.4 μm layer of gold, on the front side this prevented penetration of the laser beam into the sample, and on the back side it prevented the viewing of the IR detector onto the inside of the sample. Additionally, the samples were coated with a 5 μm graphite film to increase the energy absorbed on the laser side of the sample and to increase the temperature signal on the back side of the sample. For testing at temperatures ≥300 K, they were coated with graphite on both sides, and for <300 K the graphite coating was only on the laser side.

The measurement results are summarized in Table I. Thermal diffusivity and specific heat values are estimated to be accurate to within ±5-10%, and the calculated thermal conductivity values are estimated to be accurate to within ±7-14% with the uncertainty increasing at the lower temperatures. Two of the samples, Si and $Hg_{1-x}Cd_xTe$ x=0.24, were not measured below room temperature due to problems with mounting the samples in the low temperature sample holder. The measured values of the thermal conductivity agree quite well with the literature values (Table I). Thermal conductivity is plotted in Figs. 3 and 4. To show the data trend, the data were fit to an exponential function, and the resulting fitting parameters are listed in Table II. Thermal diffusivity and specific heat were also plotted and fit to an exponential and polynomial function, respectively. Figures 5 and 6 show the thermal diffusivity

data with an exponential fit. The fitting parameters are listed in Table III. Figures 7 and 8 show the specific heat data with a polynomial fit. The fitting parameters are listed in Table IV.

To our knowledge, these data provide the first results of thermal conductivity dependence on temperature for $Hg_{1-x}Cd_xTe$ samples with x=0.4, 0.3, and 0.24, which are materials of interest in many IR applications. Many previously published HgCdTe thermal conductivity values were interpolated from the thermal conductivity values of HgTe and CdTe. At cryogenic temperatures, this value is 20 W/m-K, an order of magnitude greater than the values measured here.[16] These measured values will be useful in more accurately modeling these materials and in implementation into real-world systems.

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Table I. Summary of Thermal Properties for InSb, InAs, Si, and $Hg_{1-x}Cd_xTe$.

Material	T (K)	c_p[a] (J/g-K) ±5-10%	K[a] (cm^2/s) ±5-10%	k (W/m-K) ±7-14%
InSb	90	0.157	0.765	67.9[a], 70[b*]
	148	0.191	0.338	36.3[a]
	298	0.211	0.135	16.0[a], 16.6[c], 19[d*]
	400	0.224	0.0951	12.0[a], 12.5[c*]
InAs	90	0.164	1.35	123[a], 130[e*]
	148	0.215	0.505	60.7[a], 69[e*]
	298	0.257	0.184	26.5[a], 27.3[f], 26.6[g*]
	400	0.268	0.122	18.3[a], 19.2[g*]
Si	298	0.720	0.839	134[a], 141.2[f], 130[h], 156[i], 128.8[j*], 142.2[k]
	400	0.821	0.539	98.4[a], 105[i], 92.5[j*], 97.4[k]
$Hg_{1-x}Cd_xTe$ x=0.40	90	0.140	0.0235	2.28[a]
	148	0.154	0.0144	1.54[a]
	298	0.176	0.00755	0.924[a]
	400	0.190	0.00579	0.765[a]
$Hg_{1-x}Cd_xTe$ x=0.30	90	0.130	0.0271	2.41[a]
	148	0.146	0.0161	1.61[a]
	298	0.176	0.00808	0.973[a]
	400	0.194	0.00596	0.790[a]
$Hg_{1-x}Cd_xTe$ x=0.24	298	0.172	0.00803	1.01[a]
	400	0.183	0.00618	0.830[a]

[a]This study
[b]Reference 6.
[c]Reference 7.
[d]Reference 8.
[e]Reference 9.
[f]Reference 10.
[g]Reference 11.
[h]Reference 12.
[i]Reference 13.
[j]Reference 14.
[k]Reference 15.
*Indicates value was estimated from a graph.

Table II. Exponential fitting parameters for thermal conductivity data, $k = k_0 + k_1 \exp(-T/\tau_1)$.

Material	k_o	k_1	τ_1
InSb	12.1 ± 1.21	199 ± 21.4	70.7 ± 6.09
InAs	19.7 ± 3.17	420 ± 73.3	64.1 ± 8.05
$Hg_{1-x}Cd_xTe$ x=0.40	0.733 ± 0.0489	4.10 ± 0.411	92.0 ± 10.3
$Hg_{1-x}Cd_xTe$ x=0.30	0.767 ± 0.0668	4.42 ± 0.589	90.5 ± 13.1

Table III. Exponential fitting parameters for thermal diffusivity data, $K = K_0 + K_1 \exp(-T/\tau_1)$.

Material	K_o	K_1	τ_1
InSb	0.104 ± 0.0152	3.24 ± 0.0500	56.5 ± 5.49
InAs	0.142 ± 0.026	7.68 ± 1.34	48.6 ± 4.61
$Hg_{1-x}Cd_xTe$ x=0.40	5.65e-3 ± 5.93e-4	0.0520 ± 0.00648	84.0 ± 10.4
$Hg_{1-x}Cd_xTe$ x=0.30	5.87e-3 ± 7.52e-4	0.0633 ± 0.00875	82.1 ± 10.9

Table IV. Polynomial fitting parameters for specific heat data, $c_p = c_0 + c_1 T + c_2 T^2$.

Material	c_0	c_1	c_2
InSb	0.120 ± 0.0292	5.29e-4 ± 2.96e-4	-6.84e-7 ± 5.98e-7
InAs	0.0918 ± 0.0298	9.78e-4 ± 3.02e-4	-1.36e-6 ± 6.10e-7
$Hg_{1-x}Cd_xTe$ x=0.40	0.121 ± 0.00567	2.38e-4 ± 5.73e-5	-1.66e-7 ± 1.16e-7
$Hg_{1-x}Cd_xTe$ x=0.30	0.106 ± 0.00368	2.90e-4 ± 3.72e-5	-1.77e-7 ± 7.53e-8

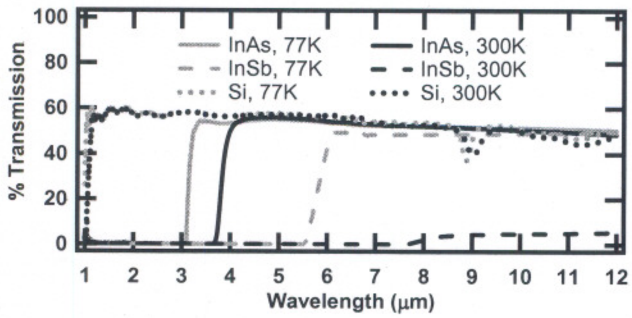

FIG. 1. Transmission spectra for InAs, InSb, and Si at 300 and 77K.

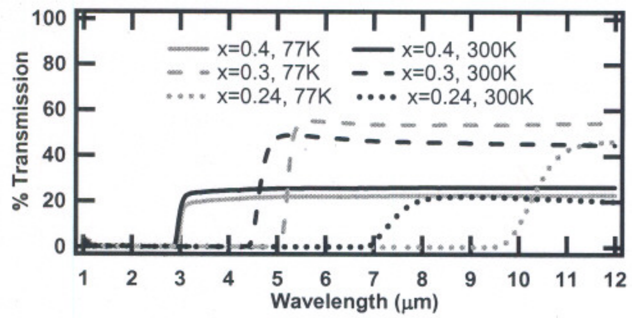

FIG. 2. Transmission spectra for $Hg_{1-x}Cd_xTe$ at 300 and 77K.

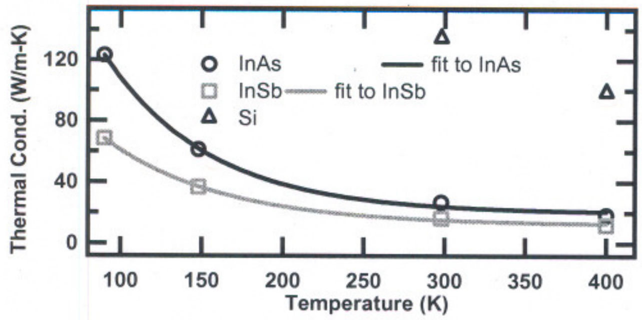

FIG. 3. Thermal conductivity of InAs, InSb and Si as a function of temperature. Exponential fit shown for InAs and InSb.

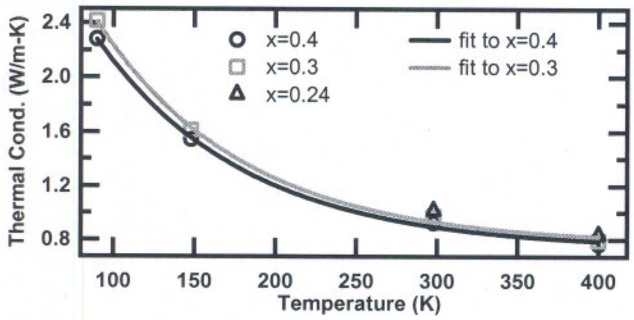

FIG. 4. Thermal conductivity of $Hg_{1-x}Cd_xTe$ as a function of temperature. Exponential fit shown for x=0.4 and 0.3.

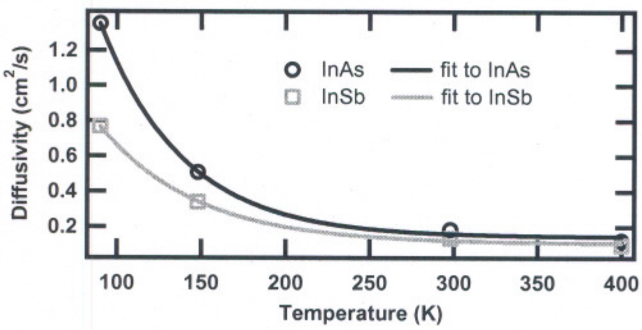

FIG. 5. Thermal diffusivity with exponential fit of InAs and InSb as a function of temperature.

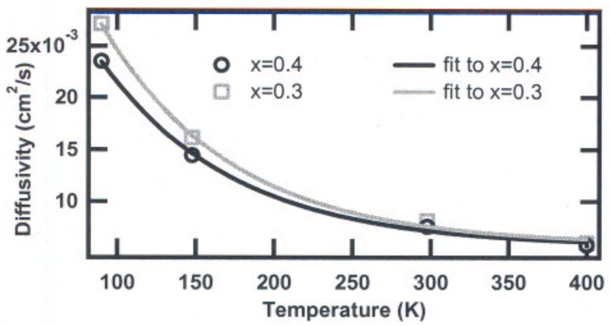

FIG. 6. Thermal diffusivity with exponential fit for $Hg_{1-x}Cd_xTe$ with x=0.4 and 0.3 as a function of temperature.

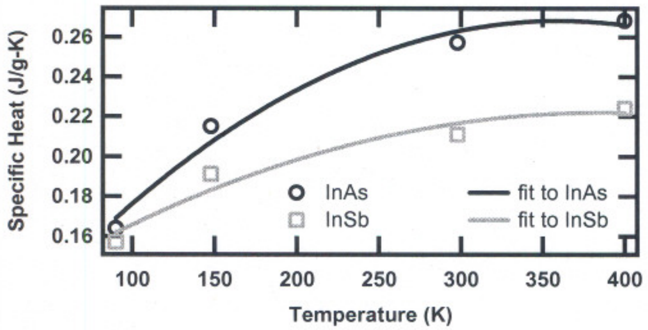

FIG. 7. Specific heat with polynomial fit of InAs and InSb as a function of temperature.

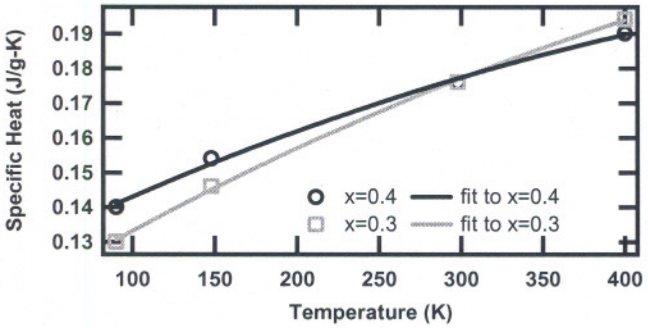

FIG. 8. Specific heat with polynomial fit for $Hg_{1-x}Cd_xTe$ with x=0.4 and 0.3 as a function of temperature.